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July 1971 / Bulletin 604T

West Virginia University • Agricultural Experiment Station

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THE AUTHORS

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Credit, also, is due former Professor of Agronomy (Hydrologist) S. L. Galpin (deceased).

THE COVER

The Virginia Furnace, pictured on the cover, is located along W. Va. Route 26, near Albright, Preston County. The furnace was built in 1852.

West Virginia University
Agricultural Experiment Station
College of Agriculture and Forestry
R. S. Dunbar, Jr., Director
Morgantown

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›oil Development on Mine Spoil[1]

R. M. SMITH, E. H. TRYON, and E. H. TYNER

RESEARCH to learn the primary physical, chemical and mineralogical properties associated with successful plant establishment and soil develop-ent on strip-mine spoils was started in 1943. It was found (19, 24, 25) that ımerous legume and grass species invaded naturally or could be established on e majority of spoils. Acidity was the primary site variable recognized as termining immediate plant survival. Grass growth was increased markedly by trogen fertilization, and both legumes and grasses responded to phosphorus on me spoil. Restricted rooting and plant wilting by some species were noted ıere fine-textured spoil was excessively packed by heavy machinery. Drouth ess was evident also where spoil was extremely stony or coarse textured.

Prior to 1940, the tonnage of coal mined by stripping in West Virginia was all. Nevertheless, regulatory legislation was passed in 1939 (1) and 1945 (2,) and at several later dates to enforce reclamation. Effective March 13, 1959, ulations were approved which permitted operators to deposit with local soil ıservation districts a sum of money estimated by the district to cover costs of egetation. Then, if the district assumed responsibility for the reclamation rk, the operator was released from this responsibility (3).

Since 1959 many stripped areas have been improved by districts as well as t the operators, guided partly by Soil Conservation Service recommendations ( ). Additional legislation has added specific requirements for spoil grading and r lamation since 1959.

Throughout the years, questions about immediate reclamation as well as the c ability of spoil to support plant growth over long periods of time inevitably h e brought to mind that an iron ore surface-mining and smelting industry fl ırished near Morgantown between 1798 and 1870 (10, 18). Since the ore was o ained by stripping mountain or hillside outcrops, an operation similar in n ıy ways to modern surface mining of coal, it was natural to seek answers ir ɔlving modern mine spoil by studying old iron ore spoil. Many of these d osits occur in relatively isolated neighborhoods where their location is known b ɔnly a few local residents or hunters.

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[1]This work is partially supported by the Federal Water Pollution Control Administrati The ideas and the conclusions are those of the authors and not necessarily those of F CA.

The spoil derived from iron ore stripping probably was low in pyrites and other reduced sulfur compounds. This is the chief difference between iron ore and some coal spoils. Much coal mine spoil also is relatively pyrite-free. The old iron ore spoil therefore offered an opportunity for study to answer questions whether satisfactory plant growth on spoil would continue for many years and whether productive soils would form on modern spoils.

This study is concerned primarily with the nature of soil found on ore spoils of known age, and with evidences regarding rates of certain rock weathering and soil forming processes. Sufficient summary information regarding plant performance and water quality is included to support conclusions about spoil properties and influences; also, a few measurements provide direct comparisons with younger coal spoils.

SITES AND EXPERIMENTAL PROCEDURES

The iron industry was centered in two neighborhoods, the Coopers Rock State Forest and the environs of Gladesville (Fig. 1). Three units, *Chestnut Ridge, Quarry Run,* and *Johnson Hollow* are located in Coopers Rock State Forest neighborhood in northeastern Monongalia County approximately ten miles northeast of Morgantown. The units occur at elevations from 1,900 to 2,300 feet above sea level on ridgetops or mountainous terrain draining steeply into Cheat Lake via Quarry Run, Johnson Hollow, Darnell Hollow, and Morgan Run. Annual precipitation averages about fifty inches, and mean annual temperature is 48° F. The spoil source consists principally of dark gray and brown shales

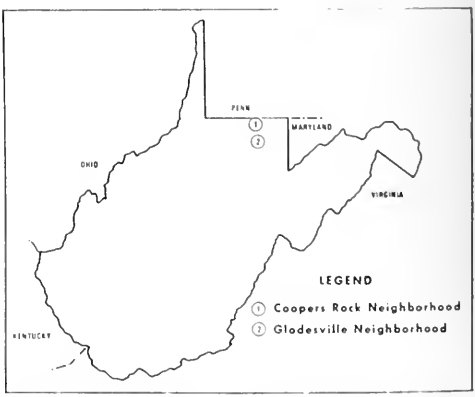

Figure 1. Location of Coopers Rock and Gladesville neighborhoods.

d ived from the Pottsville Group of the Pennsylvanian Geologic System (10). W en sampled, the age of these spoils was between 85 and 103 years. Figure 2 p tures Johnson Hollow after 100 years.

Figure 2. Johnson Hollow after 100 years.

Another three units, Glen, Massey, and Peters, occur in the Gladesville neighborhood of western Preston County approximately twelve miles southeast of Morgantown. The units are at elevations of 1,800 to 1,900 feet. The terrain is

rolling (slopes 5 to 30 per cent), with circuitous drainage down Brains Creek an Three Fork Creek into the Tygart Valley River at Grafton. Good pasture an agricultural land surround these spoils. The annual precipitation is fifty inche mean annual temperature is 52^{o} F. The spoil is derived from fine-grain sandstones and silty, brown or buff colored shales of the Allegheny Formatio of the Pennsylvanian System (10). Some limestone (called the Upper Freepo limestone) was known to occur over the iron ore but it was not found in t spoil, probably because it was used as a flux at the Irondale Furnace (10, pa 408). Such a furnace is shown in Fig. 3. The age of the spoil in this locality w between seventy and eighty-five years.

Recent strip mining of the Lower Kittanning coal in this neighborhood h provided high wall exposures of the geologic section which show dominance silty (buff and gray colored) shales, including lenses of nodular iron-ri carbonates (Fig. 4). First signs of life soon become evident on these new sp banks, as shown in Figs. 5 and 6.

Figure 3. Iron furnace restored.

Figure 4. New mine spoil and high wall.

Figure 5. First life on new spoil.

Figure 6. Life expands at bottom of high wall.

Most soils in the Coopers Rock neighborhood are stony and belong to t Dekalb series (16). These soils are classified as Typic Dystrochrepts; loar skeletal, mixed, mesic. Gilpin soils (Typic Hapludults; fine loamy, mixed, mes dominate near Gladesville but some Westmoreland soils (Ultic Hapludalfs) m occur wherever limestone or calcareous shale influences are strong. In eit locale, impervious gray clay shale parent material (often called fire clay) resu in Wharton soils (Aquic Hapludults) with characteristically mottled subs reflecting impeded profile drainage.

In comparisons with mine spoil, it should be recognized that typical s profiles developed in this region are relatively simple. Nitrogen and orga matter are highest near the surface and decrease gradually with dep Conversely, clay content is lowest near the surface and increases somewhat the subsoil (B horizon), where subangular blocky structure also is most stron developed. Such properties as pH, base saturation, and soil mineralogy are markedly differentiated with depth unless markedly different rock str constituted the parent materials.

Physical and chemical studies of soils developing on the iron ore spoils a contiguous undisturbed soils included mechanical analysis, nitrogen and profiles in each neighborhood. The profile samples were secured as follows: F

sites at each unit studied were selected to represent the particular spoil. A pit ır to eight feet long and three feet deep was dug for detailed observations and npling. Two profiles sampled with horizon thicknesses selected arbitrarily ıere horizons were not evident were taken at opposite ends of each pit. mples for each profile were kept separate; eight profiles thus were secured. e samples were air dried and weighed, crushed with a rubber tipped pestle, d screened through a ten-mesh sieve. The portion passing the ten-mesh screen 2.0 mm.) was weighed to determine the degree of shale and sandstone integration. Mechanical analysis and per cent nitrogen determinations were de on the ten-mesh portion of each sample, by the Bouyoucos hydrometer and Kjeldahl methods, respectively. Determinations of pH were made with a ss electrode pH meter using a 1:2 ratio of soil to water.

Bulk density determinations of the spoil and contiguous soil surfaces for all ts were made as follows: A cylinder six inches long with an inside diameter of ır inches was driven to full depth. The moisture in the core sample was driven at 105° C., and the net weight of the cylinder contents divided by the inder volume.

Relative water intake rates by dry and wet spoil and contiguous soil were ermined at the Peters, Quarry Run and Johnson Hollow units by the owing procedure: At five spaced points in natural soil and in mine spoil at h location, the forest litter or grass sod was removed and a soil core having a meter of three and three-quarter inches and length of two inches was ıoved. The water necessary to maintain a constant depth of one inch in the ılting two-inch deep cylindrical openings was then measured at 15, 30, 60 120 minute intervals. After the water intake rates on the initially dry spoil soil had been completed the area surrounding each hole was wetted roughly with a large volume of water. After approximately one hour, the er intake rate of the wet spoil and soil was determined.

The total nitrogen content of the surface spoil and contiguous soil at all unit ıtions was determined as follows: A cylinder six inches long with an inside neter of four inches was driven to depth. The bulk density then was ulated on an oven-dry basis as indicated previously. The samples were oved from the cylinder, ground *in toto* to eighty-mesh, mixed, and a sample yzed for total nitrogen. Thus, the results represent nitrogen adjusted for density differences for each site.

Mineralogy of Chestnut Ridge and Peters spoil and B horizons of contiguous was determined by standard processing and X-ray diffraction procedures. 500-micron fractions (fine sand and finer) were dispersed with Calgon ium metaphosphate and sodium carbonate) and reciprocal shaking for ve hours. Then the 50-micron fraction was separated by wet sieving and the)-micron fraction was separated further by sedimentation or centrifugation the following: (1) silt, 50 to 2 microns; coarse clay, 2 to 0.2 microns; and

fine clay, less than 0.2 microns. Suspensions of these fractions, after washing t remove Calgon, were evaporated on petrographic slides for diffraction analysi

The 50- to 500-micron separate was assumed to represent undisintegrate rock or "parent material." It was ground to pass a 300-mesh screen with mortar and pestle, dispersed with Calgon and reciprocal shaking, and th 2-micron fraction was subdivided into coarse and fine clay by centrifugation f forming oriented slides used to identify mineralogy by X-ray diffraction. Clay of "parent material" spoil and soil were saturated with magnesium befo evaporating on slides. Duplicates were solvated with ethylene glycol to test f interlayer expansion, followed by heating to 450° C and 500° C to determin stability of diffraction spacings.

At two woodland locations, one north- and one south-facing, paired spo and natural soil sites were used to determine moisture tension changes duri four growing seasons, by periodic (usually weekly) reading of resistances plastic-impregnated gypsum blocks (Bouyoucos-type) imbedded at differe depths in the profiles. These readings are offered as indications of relati moisture status with no attempt to convert to absolute quantities or s percentages of moisture. In fact, it is doubtful whether satisfactory gravimetr calibrations could have been established because of the high percentages of sha and sandstone constituting both the spoil and the normal soil profiles.

In general, Baver (4) has indicated that with Bouyoucos type plaster of par blocks, a resistance of 5,000 ohms approximates 4 atmospheres tension; 75,0 ohms indicates about 11 atmospheres; and 200,000 ohms about 15 atmospher tension. Kelly *et al.* (14) found wilting points to be of the order of 450,000 600,000 ohms, with very steep curves of moisture versus resistance betwe 100,000 and 600,000 ohms. This steepness probably helps explain wh approximately 90,000 ohms resistance was suggested earlier to indicate "wilting point" (5). The significant point is that, generally, increased resistan means increased soil moisture tension, or less available water.

Standard analysis of variance was used to test statistical significance differences between adjacent means in the several determinations. Levels significance indicated in tables were obtained by the F and L.S.D. tests.*

BULK DENSITIES

Table 1 shows comparisons for six units with sufficient replication establish highly significant differences between means for iron ore spoil a contiguous soil at each unit. A basis for general comparison with typical sp from coal stripping is provided by data in Table 2 representing three promine coals now being surface-mined in northern West Virginia.

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*Assistance in statistical analyses were provided by the West Virginia Univers Department of Statistics and Computer Science and the Computer Center.

TABLE 1. Bulk densities of near-surface spoil and associated surface soils.

		Bulk Density		Calculated Porosities	
N hborhood	Unit	Spoils	Soil	Spoils	Soil
		gms/cc	gms/cc	%	%
C pers Rock	Chestnut Ridge	1.48	0.90	44	66
C pers Rock	Quarry Run	1.52	1.13	43	57
C pers Rock	Johnson Hollow	1.42	0.90	46	66
G esville	Glen	1.39	1.01	48	63
G esville	Massey	1.58	1.12	40	58
G esville	Peters	1.41	1.13	47	57
	Mean	1.47	1.03	45	61

Each value is an average of four replicates.
Spoil means at each location are significantly higher (1 per cent level) than soil.

P TICLE SIZES

Surface soil textures for soils adjacent to iron ore spoils at six units are given in able 3. Detailed mechanical analyses with depth for two units of iron ore sp are given in Table 4 and 5 with eight replicates at each depth providing a sta tical test of significance of mean depth differences.

Tables 5 and 6 include coarse particles as well as conventional fine particle se ates, providing a test at two units whether near-surface weathering and soil fo ation have caused major changes since the spoil was deposited. Samples here we similar but not identical with samples represented in Table 4 and 5.

NI ROGEN

Table 2 (Appendix) includes replicate analyses for total nitrogen in the to six inches at six units of iron ore spoil and contiguous soil. Bulk densities an calculated weights per six-inch-deep acre illustrate how total nitrogen was cal lated for spoil and soil that were pulverized *in toto* for analysis.

Summary Table 2 indicates age ranges, vegetation and significance levels of me differences at each unit.

Percentages with depth through six inches for two units and continuing do ward through twenty-three inches for the Peters Unit are shown in Table 9.

TABLE 2. Bulk density in grams per cc for spoil from surface mining of coal* a
three selected locations.

Sample	Location		
	Canyon Monongalia County	Arthurdale Preston County	Kingwood Preston Count
1	1.612	1.634	1.430
2	1.638	1.772	1.518
3	1.633	1.815	1.010
4	1.396	1.723	1.546
5	1.393	1.691	1.342
6	1.583	1.663	1.274
7	0.963†	1.875	1.238
8	1.481	1.751	1.449
9	1.439	1.579	1.437
10	1.664	1.692	1.253
Average	1.480	1.719	1.350

*At Canyon, Arthurdale and Kingwood the coals involved were Pittsburgh, Upp
Freeport, and Bakerstown, respectively.
†Low bulk density caused by loose fine coal particles.

TABLE 3. Textural class of surface soils contiguous to mine spoil units.*

Peters Unit		Massey Unit		Glen Unit		Chestnut Ridge		Johnson Hollow		Quarry R	
1	2	1	2	1	2	1	2	1	2	1	2
silt laom	silt loam	loam	loam	clay loam	silt loam	loam	loam	loam	loam	loam	lo

*See Appendix Table 1 for details.

BLE 4. Mean sand, total silt, fine silt and clay percentages for the less than 2 mm. fraction at several depths in Chestnut Ridge mine spoil.*

Depth (Inches)	Sand mm 2.0 - .05 per cent	Total Silt mm .05 - .002 per cent	Fine Silt mm .005 - .002 per cent	Clay mm < .002 per cent
0-1	42.5	39.9	6.0	16.5
1-2	40.1	38.3	5.4	20.5
2-3	35.7	38.0	5.7	25.2
3-4	43.5	33.2	5.9	22.3
4-5	41.7	33.8	6.1	23.3
5-6	39.9	33.9	5.6	25.1
6-7	38.3	34.0	6.1	26.8
7-8	34.5	36.0	6.5	28.4
8-9	31.0	37.6	6.2	30.3
9-10	31.1	38.0	6.9	29.8
10-11	35.6	36.7	6.6	26.6
11-14	31.9	38.4	7.3	37.2
14-17	31.9	38.4	7.3	37.2
17-20	31.0	36.2	6.3	31.6
20-23	31.0	35.2	6.3	31.6
Mean	36.7	36.7	6.3	26.5

*Each value is an average of eight replicate pit sample determinations. Depth differences for clay are highly significant.

A IDITY

Individual and mean pH with depth in eight pit profiles at two units are pr ented in Tables 10, Appendix Table 3, 11, and Appendix Table 4, showing va itions among replicates that account for non-significant differences with de h. Means for Peters spoil are consistently higher than for Chestnut Ridge.

C TION EXCHANGE

Table 12 provides cation comparisons between samples of spoil (0- to 6-inch de h) and adjoining soil at several depths. Coarse particles (> 2 mm) were cr ied to pass the 2 mm sieve and included with fines in these determinations, ex pt pH which was determined on the fine fraction (< 2 mm) only.

TABLE 5. Mean sand, total silt, fine silt, and clay percentages for the less than 2 mm fraction at several depths in Peters mine spoil.*

	Sand mm	Total Silt mm	Fine Silt mm	Clay mm
Depth (Inches)	2.0 - .05 per cent	.05 - .002 per cent	.005 - .002 per cent	< .002 per cent
0-1	28.2	55.0	4.8	15.9
1-2	30.0	48.5	6.8	21.5
2-3	27.7	45.8	6.8	26.5
3-4	27.7	45.8	6.8	26.5
4-5	24.8	43.3	5.8	32.1
5-6	24.8	43.3	5.8	32.1
6-7	24.8	43.8	6.5	31.4
7-8	24.8	43.8	6.5	31.4
8-9	24.8	43.7	6.7	30.8
9-10	24.8	43.0	6.7	30.8
10-11	24.8	43.0	6.7	30.8
11-14	24.8	43.4	6.6	31.8
14-17	24.3	44.0	6.6	31.8
17-20	24.5	42.6	6.2	32.9
20-23	23.6	44.3	6.9	32.2
Mean	25.7	45.7	6.4	28.7

*Each value is an average of eight replicate pit sample determinations. Depth differences for clay and silt are highly significant.

MINERALOGY

Ratings obtained by standard X-ray diffraction techniques are given in Table 13 for two units, with the coarse fraction (> 2 mm) assumed to be similar to parent material from which fines were formed. Clay includes all fines with settling rates less than for 2 micron diameter mineral spheres as separated by centrifugation, being subdivided into coarse and fine clays by further separation at the 0.2 micron equivalent diameter.

Relative mineralogical ratings are given in Table 13.

Mica was rated for peaks at approximately 10, 5 and 3.33 angstroms.

Kaolinite minerals were rated on peaks approximating 7.2 and 3.57, and to some extent on lower angstrom spacings.

ABLE 6. Mean particle size distribution including coarse fragments for the Chestnut Ridge spoil.*

Depth (Inches)	Coarse Fraction >2.0 mm per cent	Sands 2.0 to .05 mm per cent	Silt .05-.002 mm per cent	Clay < .002 mm per cent
0-1	56.8	18.0	17.8	7.4
1-2	59.3	16.2	15.5	9.0
2-3	48.5	18.1	19.8	13.6
3-4	47.2	22.0	18.3	12.5
4-5	45.7	21.8	18.9	13.6
5-6	35.5	24.5	22.2	17.8
6-7	29.9	24.7	23.9	20.5
7-8	41.8	19.4	21.3	17.5
8-9	40.7	18.1	22.6	18.6
9-10	46.8	16.1	20.4	16.7
10-11	31.7	23.5	25.4	19.4
11-17	34.7	21.0	25.0	19.3
17-23	42.2	18.3	21.3	18.2
Mean	43.1	20.1	21.0	15.6

*Each value represents an average of eight replicate determinations.
Clay differences with depth are statistically significant (5 per cent level); other depth differences are not significant.

Vermiculite was rated primarily on approximately 14 angstrom peaks that w e not increased by ethylene glycol solvation and were destroyed or shifted by h ting to 500° C. Higher order spacings also were noted.

Quartz was rated on peaks approximating 4.29, 3.36 and 1.82 angstroms.

In Peters spoil, coarse clay, and Peters subsoil, coarse clay and fine clay, a 6. 2 to 6.37 angstrom spacing was rated as unknown. Some other low angstrom sp ings either were high order spacings of identified species, or in some cases pe aps represented unknown species or mixed layering.

Expanding lattice clays were eliminated by absence of basal spacing in eases of the 14 angstrom peaks with ethylene glycol solvation.

Chlorite was eliminated by absence of 14 angstrom peaks that remained st le when heated to 500° C and absence of the exceptionally sharp 7 angstrom pe following heating which helps characterize chlorite. If present, in small qu ntities, chlorite was not distinguished.

TABLE 7. Mean particle size distribution including coarse fragments with depth for the Peters spoil.*

Depth (Inches)	Coarse Fragments > 2.0 mm per cent	Sands 2.0 to .05 mm per cent	Silt .05-.002 mm per cent	Clay < .002 mm per cent
0-1	47.2	14.9	29.6	8.3
1-2	47.7	15.7	25.4	11.2
2-4	53.3	12.9	21.4	12.4
4-6	58.3	10.3	18.6	12.8
6-8	64.8	8.7	15.2	11.3
8-11	61.1	9.7	17.0	12.2
11-14	62	9.3	16.7	11.6
14-17	66.2	8.2	14.7	10.7
17-20	69.1	7.6	13.2	10.1
20-23	66.4	7.9	14.9	10.8
Mean	59.8	10.5	18.7	11.1

*Each value represents an average of eight replicate determinations. Differences with depth are not statistically significant.

INFILTRATION

Accumulated infiltration into standard cylindrical holes, first at the field moist (dry) condition and later following soaking (wet) are summarized for three units in Table 14. Individual rates for the second (final) hour of the wet runs are given in Table 15, with significant differences identified.

FIELD MOISTURE TRENDS

Figures 7, 8 and 9 show plastic coated plaster block resistance readings at five depths throughout three growing seasons. Data for a fourth season were omitted because of similarity to the previous year. Readings presented are averages for two distinct units, each of spoil and soil (control), forested, and separated by about one mile in similar geologic material in the Coopers Rock neighborhood.

Table 6 Appendix provides rainfall information for Brandonville, Preston County, confirming the seasonal differences involved in explaining soil moisture trends.

TABLE 8. The nitrogen content of spoil versus associated soil, including vegetation and estimated age of spoil units.

Unit	Nitrogen/acre* (6-inch depth) Spoil	Nitrogen/acre* (6-inch depth) Soil	Significance** of treatment difference	Dominant present vegetation	Probably dominant vegetation over time	Estimated age	Approximate acre*** Increase Annually in spoil
	pounds	pounds				years	pounds
Chestnut Ridge	2,430	2,844	HS	Forest	Forest	85-119	23
Glen	2,533	3,105	HS	Forest	Forest	72-83	31
Johnson Hollow	1,900	2,046	NS	Forest	Forest	85-131	18
Massey	1,756	2,069	S	Grass	Grass	72-83	23
Peters	2,438	2,765	S	Grass	Grass	72-83	31
Quarry Run	2,520	2,596	NS	Forest	Forest	85-119	25

*Each value is an average of four replicates based on actual bulk density determinations.

**S and HS indicate 5 per cent and 1 per cent levels of statistical significance, respectively, between soil and spoil at several locations. NS indicates non-significance at the 5 per cent level.

***Approximate acre increases annually are based on the assumption that nitrogen increases below six inches are equal to nitrogen present in the top six inches of original spoil.

TABLE 9. Per cent nitrogen in the finer than 2 mm fraction (weight basis) wit depth in iron ore spoil at two units.*

Depth (Inches)	Nitrogen Chestnut Ridge	Peters
	per cent	per cen
0-1	0.296	0.567
1-2	0.141	0.269
2-3	0.084	0.170
3-4	0.074	0.112
4-5	0.078	0.100
5-6	0.069	0.095
6-8		0.090
8-11		0.085
11-14		0.080
14-17		0.075
17-20		0.079
20-23		0.079

*Each value is an average of eight replicate sample determinations.

LEAF COMPOSITION

Table 16 shows paired comparisons of leaves of several plant specie collected for chemical analysis from six different spoils and contiguous soil together with statistical significance among means.

ROOT DEVELOPMENT

Results here were taken largely from previous publications (23, 26).

Detailed root charting by size classes in pits was carried out at the Chestnu Ridge and the Johnson Hollow units, with root diameters in inches indicated i Figures 10, 11, 12, and 13 by the following symbols: $<0.05=$. ; 0.05 - 0.1 = ○ 0.1 - 0.2 = △ ; 0.2 - 0.5 = ⊙ ; 0.5 - 1.0 = x; 1.0 = ⁙ (drawn to scale); dead root = ● Sandstone fragments were indicated by cross hatching.

SITE QUALITY

The site quality of spoils and adjacent soils was measured at the Chestnu Ridge, Quarry Run, Johnson Hollow and Glen units. The site index metho involved heights of dominant and co-dominant trees at the mode-age, which i

ABLE 10. **pH profile of Peters mine spoil in grass pasture in the Gladesville Neighborhood.***

Depth (Inches)	pH (Mean)
0-1	5.69
1-2	5.24
2-4	5.19
4-6	5.13
6-8	5.07
8-11	5.06
11-14	5.09
14-17	5.07
17-20	5.01
20-23	5.02
Mean	5.16

*See Appendix Table 2.

t age of the greatest number of sample trees on the unit. Species chosen to test s quality were commercially important and were present both on spoil and s l. In all cases the age of the majority of the trees was close to the mode.

F STURES

Two spoils (Massey and Peters) used for pasture were compared in terms of f ige species represented and forage yields in protective cages. On Peters spoil d irable forage species [2] provided 57 per cent of the ground cover compared to 4 per cent on adjacent natural soil. Clipping yield from three replicate cages d ing one grazing season on spoil was 800 grams per square meter and 715 g ns on soil. Surface soil pH values were 4.85 on the spoil and 5.05 on soil, su porting claims of neighborhood residents that the land had not received lime o ertilizer treatment. A general view of pasture on Peters spoil is shown in Fig. 1

[2] Desirable species consisted of: Kentucky bluegrass (*Poa pratensis* L.), Canada bluegrass (*P compressa* L.), White clover (*Trifolium repens* L.), Lowshop clover (*Trifolium p umbers* L.), Redtop (*Agrostis alba* L.), Timothy (*Phleum pratense* L.).

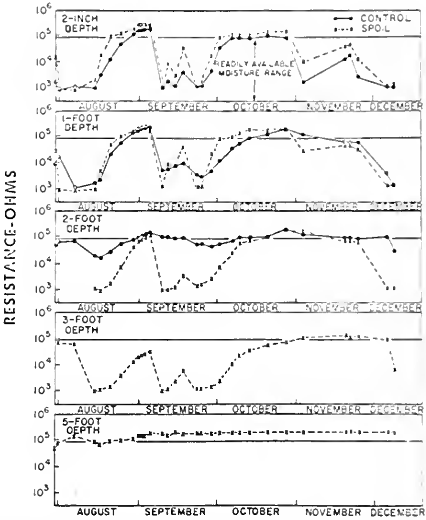


Figure 7. Soil moisture tension trends in ohms resistance of gypsum blocks in forested soil and spoil during a dry season.

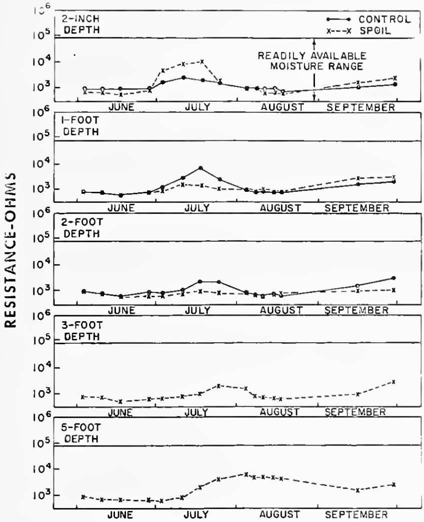
On the Massey Unit, also believed to be unlimed and unfertilized, desirable forage species were 73 per cent on the spoil and 24 per cent on soil; clipping yields were 697 grams on spoil and 451 grams on soil; surface pH of the spoil was 5.91 and for soil 4.99.

Discussion and Interpretations

BULK DENSITY AND POROSITY

Data indicate conclusively that 70 to 130 years was not long enough for shaly iron ore spoils to develop bulk densities as low as natural undisturbed soils. This means that porosity of the surface spoil was significantly less than porosity of non-disturbed surface soils at each of the six different units sampled.

Three reasons for the higher bulk densities and lower total porosities of mine spoil are evident. First, the spoil contains higher percentages of rock (shale and sandstone) fragments; second, the rock fragments in spoil tend to be less weathered and less porous than rock fragments in the natural soils; and third, soil structure in the fines of the mine spoil is absent or only weakly developed



gure 8. **Soil moisture tension trends in ohms resistance of gypsum blocks in forested soil and spoil during a moist season.**

hereas soil structure in natural soils is more distinct (moderately developed) as result of more organic matter and greater biological activity (27) as well as her structure forming influences. These three differences between old mine oils and natural soils cannot be expressed quantitatively at present but they e unequivocal.

Porosity differences calculated from bulk densities and specific gravities of e minerals involved may be visualized as follows: bulk densities of 1.32 rrespond to porosities of about 50 per cent; bulk densities of 1.00 indicate rosities approximating 60 per cent; and bulk densities of 1.60 indicate rosities of 40 per cent.

Comparisons with mine spoil from recent surface mining coal show bulk nsities similar to those for the old iron ore spoil (Table 2). Evidently there has en only slight change in bulk density and porosity during more than seventy ars of soil formation.

ARTICLE SIZE AND WEATHERING

Undisturbed surface soils (Dekalb and Gilpin series) adjoining six mine spoil its in this study were loam, silt loam, or clay loam (one site in the Glen Unit).

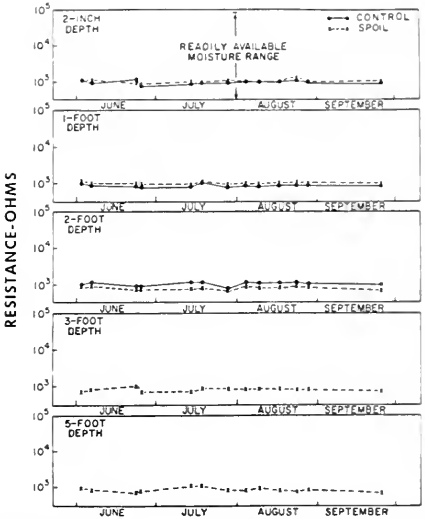
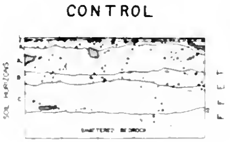


Figure 9. Soil moisture tension trends in ohms resistance of gypsum blocks in forested soil and spoil during a wet season.



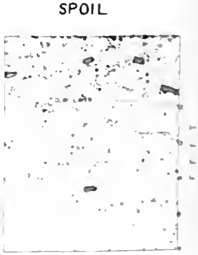


Figure 10. Root distribution in normal soil, Chestnut Ridge Unit.

Figure 11. Root distribution in old mine spoil, Chestnut Ridge Unit.

TABLE 11. **pH profile of Chestnut Ridge mine spoil in forest in Coopers Rock neighborhood.***

Depth (Inches)	pH Mean
0-1	4.33
1-2	4.26
2-3	4.41
3-4	4.45
4-5	4.43
5-6	4.39
6-7	4.39
7-8	4.51
8-9	4.23
9-10	4.51
10-11	4.64
11-17	4.35
17-23	4.65
Mean	4.42

*See Appendix Table 3.

CONTROL

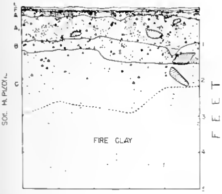


Figure 12. Root distribution in normal soil, Johnson Hollow Unit.

SPOIL

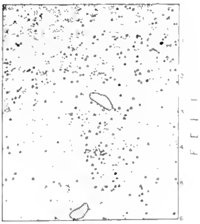


Figure 13. Root distribution in old mine spoil, Johnson Hollow Unit.

TABLE 12. Summary of cation-exchange and related characteristics of spoil and of the A and B horizons of contiguous soils.

Material*	Depth	Soil Horizon	Total 2.0 mm material	pH	Organic carbon	<2 u Clay	Cation exchange capacity	Exch. Ca	Exch. Mg	Exch. K	Base Saturation
	inches		per cent		per cent	per cent	mg/100 g.	mg/100 g.	mg/100 g.	mg/100 g.	per cent
					PETERS UNIT						
Spoil	0-6	A_1	70	5.4	(2.0)**	(11.0)**	11.6	3.08	0.96	0.19	36.5
Undisturbed soil	0-1	A_{p1}	64	5.0	6.4	6.9	23.3	8.32	1.81	0.36	45.0
" "	1-4	A_{p2}	78	4.8	4.1	10.5	14.0	1.79	0.91	0.17	20.5
" "	4-5	A_{p3}	78	4.9	2.6	12.1	11.3	1.71	0.36	0.14	14.8
" "	5-10	B_1	72	4.8	1.4	13.7	7.8	1.00	0.26	0.09	17.3
" "	10-18	B_2	55	4.3	0.3	16.0	5.1	0.94	0.13	0.07	22.4
					CHESTNUT RIDGE UNIT						
Spoil	0-6	A_1	66	4.3	(1.8)**	(12.3)**	6.80	0.66	0.33	0.13	16.5
Undisturbed soil	0-1	A_1	51	4.11	6.4	74.	13.7	0.97	0.31	0.16	10.5
" "	1-5	A_2	50	4.62	2.0	8.6	6.9	0.25	0.08	0.11	6.4
" "	5-8	A_3	48	4.62	1.2	8.9	4.6	0.19	0.10	0.09	8.3
" "	8-18	B	60	4.42	0.7	14.5	4.4	0.27	0.08	0.09	10.0

*Except for pH all chemical and physical data reported on entire sample basis.
**Percentages in parentheses are approximations based on averages for adjacent spoil samples.

TABLE 13. Summary of relative mineralogical ratings.*

Chestnut Ridge Spoil	Mica	Koa	Verm.	Quartz	Unknown
Assumed Parent Material	2	2	–	2	–
Silt	3	3	1	3	–
Coarse clay (2-0.2 micron)	3	3	1	3	
Fine Clay (< 0.2 micron)	3	3	1	1	–
Chestnut Ridge, Normal Subsoil					
Assumed Parent Material	2	2	–	2	–
Silt	2	2	2	2	–
Coarse clay (2-0.2 micron)	1	3	3	1	–
Fine Clay (< 0.2 micron)	–	3	3	1	–
Peters (Gladesville) Spoil					
Assumed Parent Material	2	2	–	2	–
Silt	2	2	1	3	–
Coarse clay (2-0.2 micron)	2	2	2	2	1
Fine Clay (< 0.2 micron)	2	2	2	1	–
Peters (Gladesville) Normal Subsoil					
Assumed Parent Material	2	2	–	2	–
Silt	2	2	1	3	–
Coarse Clay (2-0.2 micron)	3	3	3	2	1
Fine Clay (< 0.2 micron)	2	2	2	1	1

*Minerals are Mica; Kaolinite; Vermiculite; Quartz; and Unknown (does not correspond with any known species spacing). Ratings refer to relative heights of first, second and third order spacings: 1=weak, 2=medium; 3=strong.

ıbsoils below 8 to 12 inches would be loam or channery loam for typical ·kalb and clay loam, silty clay loam, or shaly silty clay loam for Gilpin (16). ıestnut Ridge and Peters mine spoils (< 2 mm fraction) both averaged clay ım (>28 per cent clay) below the surface two inches. Coarse particles (> 2 n), etc., in these spoils averaged 60 per cent by weight for Peters and 43 per

TABLE 14. Accumulated inches water intake of spoil and adjacent soil.*

	Peters Unit				Johnson Hollow Unit				Quarry Run Unit			
Time	Spoil		Soil		Spoil		Soil		Spoil		Soil	
Minutes	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
15	2.4	2.8	3.8	6.2	6.0	1.9	8.4	3.7	6.4	3.51	10.4	3.2
30	3.2	4.4	6.2	11.7	9.4	2.7	14.3	5.4	10.6	5.83	16.7	6.1
60	4.7	8.0	11.1	22.4	15.4	4.3	25.5	9.7	18.6	11.4	27.0	11.0
120	8.0	15.0	22.0	42.1	25.0	7.8	42.6	18.2	31.1	20.4	43.0	17.7

*Each value represents average of five replications.

TABLE 15. Mean final 60-minute infiltration rates, wet run.*

	Treatment	
Unit	Spoil (in. per hr.)	Normal Soil (in. per hr.)
Johnson Hollow	3.52	8.54
Quarry Run	9.00	6.64
Peters	7.02	19.76
Mean	6.51	11.65

*See Table 5, Appendix.

cent for Chestnut Ridge, which are considerably higher than normally found in most Gilpin, Dekalb and related surface soils, and somewhat higher than in Gilpin subsoils. In Dekalb, by definition, the percentage of coarse particles from 10 inches depth to a lithic contact is 35 per cent or more by volume (usually more than 50 per cent by weight, depending on rock porosity) which is similar to the iron ore spoils.

Mean percentages of coarse particles in the spoils were not significantly influenced by depth to 23 inches. Assumed greater intensity of weathering near the surface has not measurably reduced percentages of coarse particles (Tables 5 and 6).

Considering the fine fraction (< 2 mm.) only, clay is significantly lower in the surface two inches of Chestnut Ridge and Peters spoils, and silt is significantly higher in the surface of Peters spoil (Table 4) than at greater depths

[illegible] leaves of plants grown on spoil and contiguous soils.*

Unit	Species	Nitrogen		Phosphorus		Potassium		Magnesium		Calcium	
		Spoil	Soil	Spoil	Soil	Spoil	Soil	Spoil	Soil	Spoil	Soil
Chestnut Ridge	Sassafras (leaves)	2.85	3.36	0.185	0.168	2.74	2.28	0.297	0.236	1.10	1.06
Johnson Hollow	Sassafras (leaves)	3.36	3.00	0.165	0.150	2.16	1.94	0.268	0.176	0.94	0.86
Quarry Run	Sassafras (leaves)	2.26	2.66	0.155	0.158	2.58	2.38	0.208	0.184	1.05	0.78
Quarry Run	Yellow Poplar (leaves)	2.74	2.67	0.180	0.145	1.84	1.55	0.484	0.468	0.81	0.94
Glen	Dogwood (leaves)	1.89	2.12	0.188	0.155	1.60	1.74	0.728	0.620	2.42	2.03
Peters	Poverty grass	1.14	0.99	0.075	0.075	1.18	1.22	0.088	0.096	0.27	0.77
Massey	Wild carrot (single leaves)	2.14	2.00	0.235	0.165	2.87	2.80	0.260	0.304	1.47	1.26
Mean	All	2.34	2.40	0.169	0.145	2.14	1.99	0.333	0.298	1.15	1.10

*Means for nitrogen, potassium, calcium, and magnesium are not significantly different (5 per cent level) on spoil versus soil; means for phosphorus are significantly different at the 5 per cent level, with higher phosphorus for plants grown on spoil.

Figure 14. Peters spoil in pasture.

Evidently soil forming processes have moved measurable but relatively smal quantities of clay downward in the profiles. However, soil structure of the < 2 mm. fraction was very weak blocky or massive below the top few inches, and no clay skins or other clear evidences of illuvial clay were observed, although some apparent pressure faces of incipient peds might involve sufficient illuviated clay to account for that removed from the top two inches of the spoil.

NITROGEN AND ORGANIC MATTER

There was considerable variation in total nitrogen for different replicat samples from each of six units of spoil and adjacent soil. The high bulk densitie of the spoil result in less difference between spoils and soils on a weight-per-acr basis than on a percentage basis. Since all coarse particles were pulverized an included in analyses, the adjustment for actual bulk density of each sample wa necessary.

The summary of nitrogen per six-inch depth over an acre (Table 8) showed range from 82 per cent (Glen) to 97 per cent (Quarry Run) for spoil compare to undisturbed soil. If spoil originally was void of nitrogen, or if nitroge increase below six inches is assumed to be essentially equal to nitrogen originall

present in the top six inches, then average rates of increase per acre varied from 18 to 31 pounds, annually, with no differences associated with dominant present vegetation. On Peters and Massey spoil, white clover could account for part of the nitrogen accumulated. On the four forested units, black locust, although low n abundance, presumably contributed small amounts of nitrogen to the spoil naterial.

Appreciable nitrogen continued downward in spoil at least to a depth of 23 nches (Table 9). Percentages in Peters spoil below six inches were similar to percentages in undisturbed soils of this region (12). Without measurements of coarse particles (> 2 mm.) and bulk densities the percentages cannot be converted to pounds per acre. However, the total quantity below six inches may be as great as quantities within the top six-inch depth.

Estimated rates of nitrogen accumulation in spoil were similar to annual ates of nitrogen accretion (20 to 30 pounds per acre) reported for surface soils t midwestern (Missouri and Illinois (28)) and southwestern (21) locations where legume influences were absent or small. Much more rapid accumulation is much as 300. pounds per acre, annually) from an adopted legume occurred in esurfaced Oxisols in the tropical climate of Puerto Rico (20); and 100 pounds r more accumulated in fresh volcanic ash of St. Vincent (9). Jenny (13) :edited abundance of legumes for high natural nitrogen accumulation in some opical soils.

On coal mine spoil near Canyon, three miles northeast of Morgantown, trogen accumulated at a rate of approximately 100 pounds per acre annually. his acid spoil originally was treated and seeded to legumes and grasses in 1943 9, 24, 25). When sampled in 1969 the quantities of nitrogen in the top six ches amounted to 2,190, 2,380, and 2,950 pounds per acre at three points in e plot area. The forage stand in 1969 included birdsfoot trefoil (*Lotus rniculatus* L.), mixed grasses and low growing forbs, plus a small percentage of d clover (*Trifolium pratense* L.), white clover (*Trifolium repens* L.) and alsike over (*Trifolium hybridum* L.).

An additional influence here was grazing with cattle and some winter eding of cattle on the spoil after the grazing season. It is uncertain how much rogen came from legumes and how much from animal manure or other urces. The accumulation was approximately four times the rate determined in the surface six inches on older iron ore spoil, and present quantities per acre, er 25 years, are similar to quantities in natural local soils (12) and the 100 urs old spoil.

Studies on basal slopes of Mount Shasta, California, at an elevation of 3,700 ft, mean annual precipitation of 46.6 inches, mean annual temperature of 46^{o} F, and mean growing season of 94 days provides additional comparisons in the-dated mud flows of volcanic tuff-breccia under luxurious growth of western yellow pine (*Pinus ponderosa* Douglas) (6).

Under these conditions a total nitrogen maximum in the ecosystem (including both soil and litter on the forest floor) to a depth of thirty-six inches was reached in 205 years, after which (through 1,200 years) there was a slight decline, possibly representing distribution downward below 36 inches (7). The maximum of 2.7 grams per 0.05 square foot, recalculated amounts to 5187 pounds per acre or an average annual accumulation rate of 25.3 pounds, 74 per cent in the soil and 26 per cent in the litter on the forest floor. Also, other soil properties with development similar to nitrogen (or total organic matter) were bulk density (lower), color (darker), moisture characteristics (improved), and exchange capacity (increased).

ACIDITY (pH) PROFILES

Detailed pH measurements at two spoil units show variations with depth and from pit to pit of more than 1.0 pH units and maximum mean pH at the immediate surface in Peters spoil, but no differences with depth consistent enough for statistical significance. Apparently, leaching, organic litter deposition on the surface and other soil forming processes have failed to differentiate pH horizons clearly during 70 to more than 100 years. Original rock composition for moderate random pH differences at each of the two locations, and a mean difference of 0.8 between the two locations.

pH ranges in old iron ore spoils are similar to pH in natural Dekalb and Gilpin soils (12, 16) except for a few extremely low values randomly spaced in Chestnut Ridge spoil. Evidently long-time soil forming processes do not change soil horizon pH appreciably in this region when the soil material is within the acid range. Deposition of bases in deciduous litter on the surface and downward movement by leaching tend to counteract, with neither process demonstrating dominance during approximately 100 years. Moreover, no marked, consistent pH differentiation with depth typifies fully developed normal soils of this region (12, 16).

Six extremely acid pH values (less than 4.0) recorded in Chestnut Ridge spoil might reflect significant quantities of pyrite or other acid-forming minerals in the rock, similar to some coal overburdens.

CATION EXCHANGE AND PLANT NUTRIENTS

Exchange capacities and bases were lower for iron ore spoil than for the top inch of natural Dekalb and Gilpin soils. Below the four- or five-inch depth consistently, and in a number of cases below one inch, the exchange capacities bases and base saturations for natural soil horizons were lower than for zero- to six-inch deep composits of the spoil.

Superiority of the top inch of soil was associated with a natural concentration of soil nitrogen in organic matter. Below the shallow depth of organic matter concentration, the lower exchange capacities, bases and per cent

base saturation in natural soil reflected normal weathering, leaching and soil formation in this humid temperate climate over long time intervals. Relatively fresh spoils, on the other hand, although derived from non-calcareous acid shales and fine grained sandstones, retained somewhat more basic elements (calcium, magnesium, and potassium) than the mineral fraction of natural soils.

Obviously, it is possible that original character of parent materials of the natural soils was not identical with rock materials of the iron ore spoils in these two neighborhoods. However, comparisons suggest that differences between natural soils and spoils can be accounted for by natural weathering and soil forming processes without assuming significant differences between parent materials of soils and spoils.

MINERALOGY AND WEATHERING

The clay-sized (< 2 micron) fraction of pulverized rock fragments assumed to be parent material or iron ore spoils and soils contained little or no vermiculite or other 14 angstrom minerals. Mica (or illite), kaolinite and quartz, on the other hand, were present in all cases. Vermiculite appeared in all fine separates of spoils and subsoils, and was prominent in the clay and fine clay (< 0.2 micron) fractions of both subsoils as well as in the Peters spoil.

Mica disappeared in fine clay of the Chestnut Ridge (Dekalb) subsoil whereas vermiculite showed strong peaks. This trend with particle size could be interpreted as following the weathering sequence suggested by Jackson *et al.* (1), with weathering of mica in parent material through mica intermediates to vermiculite.

Similarity of mineralogy in comparatively young Peters spoil and contiguous mature (Gilpin) subsoil, both in pasture, suggests that mineralogy at the Peters location may be inherited from disintegration of parent rock. This explanation would require disintegration of shales or sandstones containing vermiculite to clay size particles but resistance to disintegration by rock containing little or no vermiculite since the coarse fragments assumed to typify parent material were free of vermiculite. Alternatively, if coarse fragments typify the parent rock, weathering to vermiculite took place within 72 to 83 years.

The disappearance of mica in Chestnut Ridge (Dekalb) normal subsoil but not in spoils probably reflects the much longer time involved for normal mature soil formation than represented since exposure of the iron ore spoils. Persistence of mica in Peters (Gilpin) subsoil may be related to higher pH inherited from limestone and base saturated shales in the parent rock in contrast to lower pH from acid parent sandstones and shales with no limestone influence at Chestnut Ridge.

Significant variations of peak heights among spoil and soil separates may reflect variable dilution by undetermined X-amorphorus constituents.

Unidentified peaks from 6.32 to 6.37 angstroms in Peters (less acid) spoil and natural subsoil but not in Chestnut Ridge (more acid) materials suggest a weathering difference associated with acid base status.

Mt. Shasta, California, studies showed scant evidence of any mineralogical change in the clay fraction. This indicated how slow the formation of secondary clay minerals must be, if it occurs at all, in such an environment (8). This conclusion is consistent with relatively minor mineralogical change over time noted here in soils compared to mine spoils and assumed parent materials, especially with only moderately-strong acidity.

INFILTRATION, DRY AND WET

Considerable variation occurred among replicate infiltration sites in each of the three units of spoil and soil. Such variations are normal, especially in materials with high percentages of coarse particles. Even so, replication was sufficient to establish significantly higher final infiltration rates for soil than for spoil, at the Peters and the Johnson Hollow units. Also, both for dry and wet runs cumulative intakes at these two units were higher for natural soils than for spoils. At the Quarry Run Unit there were no significant differences between soil and spoil. One extremely high final wet intake on spoil accounted for the higher wet mean intake on spoil. Such a high value relates to opening of channels in the coarse material and not to any consistent property of the spoil versus soil. Without this one measurement, infiltration would have averaged higher but not significantly so, for soil, both for dry and wet runs.

The tendencies for higher water intake into soils even though spoils contained higher percentages of coarse particles, appeared to be a result of subangular blocky structure development in natural subsoils in contrast to the massive matrix of weathered shaly spoils where aggregation and organized structure were absent or weak because of limited time for biological action (27), and influences of other soil structure forming processes. In these spoils there were a few widely-spaced partings apparently related to penetration of shrinkage with drying from the surface downward. These partings, or incipient ped faces, appeared to reflect pressures of swelling following shrinkage rather than illuvial clay. However, data indicate measurable movement of fine clay downward from the top few inches. This fine clay, being mobile downward, might be accumulating on the observable parting faces mentioned, although data were not precise enough to establish that clay illuviation was occurring at any particular depth.

FIELD MOISTURE TRENDS AND RAINFALL

Although it is recognized that moisture tension (negative moisture potential) as estimated with plastic-coated gypsum blocks cannot be precisely stated in terms of mass of water available for plant growth, it is impressive tha

these resistance blocks indicated moisture conditions through four growing seasons that were consistent with moisture from rainfall, depth of active plant rooting, and performance of woody species.

During the first season, with monitoring starting at the last of July, moisture tension indications were similar for mine spoil and soil at two inches and at one-foot depths. At two feet mine spoil showed generally less soil moisture stress (more moisture) especially during September. And at the 3-foot depth mine spoil apparently contained plant available moisture whereas in natural soil profiles bedded rock strata prevented root penetration or placement of tension blocks. This was a relatively dry year during which available moisture at three feet or deeper might have been significant for survival and growth of established perennials.

The second season involved essentially normal rainfall (Table 16), and block readings suggested adequate moisture throughout the growing season, both in soil and mine spoil. In spoil, to be sure, there were apparent reserves of readily available moisture because of its greater depth.

During the year shown in Figure 9, a relatively wet season, there was no indication of moisture stress, either in soil or mine spoil, but there were depth reserves in the mine spoil. The same result was recorded during the previous season, with lower, but apparently adequate rainfall.

EAF COMPOSITION AND AVAILABLE NUTRIENTS

Since plant nutrient deficiencies commonly limit growth of pasture species d other crops in West Virginia (12, 17), it appeared appropriate to check iether plant composition as an indication of plant nutrient status would licate consistent differences between plants growing on natural soil and those owing on iron ore spoil.

It was not always possible to find plants of the same species, age and stage growth on contiguous soil and mine spoil for sampling and composition nparisons.

Seven selected comparisons for non-legumes are presented in Table 16. ree cases are sassafras (*Sassafras albidum* (Nuttall) Nees); one yellow-poplar (*riodendron tulipifera,* L.); one dogwood (*Cornus florida,* L.); one poverty grass (*nthonia spicata* [L.] Beauv.); and one wild carrot (*Daucus carota,* L.).

Generally, the nutrient contents in paired comparisons between natural soils a ore spoils were similar. However, in five of seven comparisons phosphorus, p assium, magnesium and calcium were higher for plants grown on mine spoil. T mean of seven total nitrogen comparisons was higher for plants grown on n ural soil than on mine spoil. Analysis of variance, not considering plant s ies differences, indicated that the phosphorus mean was higher for plants g vn on mine spoil (5 per cent level). Other means were not significantly

different, with four higher for plants on mine spoil, and one (nitrogen) higher for plants grown on natural soil.

Since phosphorus and nitrogen are the two most commonly deficient plant nutrients recognized in West Virginia soils, it is noteworthy that plants on old spoil were significantly higher in phosphorus and lower (not significantly) in nitrogen, the nutrient shown to be significantly lower in the top six inches of spoil than in natural contiguous soils.

ROOT DISTRIBUTION AND DEVELOPMENT

At Chestnut Ridge the soil terminated in bedrock sandstone and shale at an average depth of 33 inches. Below this depth there was no significant root development. Contiguous spoil was deeper than 72 inches and tree roots were found through that depth. The top 24 inches of natural soil contained 94 per cent of the total counted roots; the same depth of spoil contained 57 per cent. Total relative numbers of roots were 923 in spoil and 641 in natural soil. Root distribution is shown in Figures 10 and 11.

At the Johnson Hollow Unit the effective soil depth was between 26 and 36 inches in the pit dug for root studies, where the soil profile terminated in bedded, acid gray clay shale. Above this depth, low chroma mottling was evident, indicating impeded drainage.[3] The adjacent spoil, as at the Chestnut Ridge Unit, was greater than 72 inches deep. Root numbers recorded were 1,101 in the spoil and 787 in the soil, with roots all less than 36 inches deep in the soil. Although root counts were not made below 72 inches the pit in spoil was deepened to 102 inches where a very few roots were evident. Figures 12 and 13 show roots charted to 72 inches.

FOREST SITE QUALITY RATINGS

Site quality comparisons show clearly that there was no consistently significant difference between spoils and natural soils during the time represented. Since nitrogen and organic matter initially were low in spoil and increased gradually after tree establishment, it is apparent that the site index comparisons involve spoils containing less nitrogen and organic matter than at present.

PASTURE QUALITY AND POTENTIALS

Observations during these studies indicated that grazing horses and cattle preferred the forage growing on spoil. This preference could have been a reflection of the greater abundance of white clover and bluegrasses on the spoil, or it could have related to a higher content of certain nutrients, since plant analyses indicated that phosphorus content was higher for plants on spoil than

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[3]Soil in the pit would be classified as Wharton silt loam.

ɔn natural soil, and other mineral nutrients showed a similar though ıon-significant tendency.

Greater depth of spoil compared to natural soil should provide greater ›pportunity for deep-rooting forage species to obtain available water and nineral nutrients if such species were introduced by seeding.

'OPOGRAPHY, EROSION, AND DRAINAGE WATER QUALITY

As with modern surface mining of coal in steep terrain, the old iron ore perations commonly left an up-slope rock cut or high wall where overburden n the hillside became too deep for profitable removal. Thus, a topography was reated, consisting of the high wall (from a few feet to as much as 30 feet high) ıd a contour bench (as wide as 40 feet) of low mounds ranging from undulant aces to rounded knobs several feet high. Small concavities among the mounds ı gentle slopes were capable of significant surface detention of runoff. owever, no evidence of semi-permanent ponding was observed.

Downslope from relief points between knobs, small fan-like deposits ›parently represent local water erosion before invasion by vegetation, but no diment has filled any of the natural v-shaped intermittent drainageways leading to permanent streams.

In the Coopers Rock neighborhood, where gradients of Quarry Run and hnson Hollow are 300 to 500 feet per mile, the rapid flow of water keeps fine rticles removed and pebbly Pottsville sandstone exposed to scour. If any old ne spoil eroded into these channels it was transported downstream into the eat River. Normal flow is free of observable sediment (Fig. 15). Water samples llected in November, 1969, at near-normal flow were clear, with pH of 6.3 and ctrical conductivity of 16×10^{-5} mhos., indicating less than 100 parts per mil- n (very low) concentrations of soluble salts. Iron and nitrogen concentrations re less than one part per million (very low); sulfate concentration was 16 parts million (low).

The Gladesville neighborhood drains into Brains Creek, some reaches of ich have low gradients where this small stream is perched on erosion-resistant tsville sandstone strata. The geologic situation has resulted in stream ındering and a gently-sloping, poorly-drained alluvial valley wide enough to lify as glade land and distinctive enough to name the neighborhood.

The upper reach of Brains Creek, below the old iron ore spoils, typifies le land (Fig. 16). However, drainage has been improved by stream-straighten- and vegetation for productive pasture has been encouraged by brush re- al, liming and fertilization. In this situation there is no evidence of sediment led from the iron ore spoils. Samples of local seepage and runoff from the l units into upper Brains Creek in November, 1969, were clear, with pH of 5.6 electrical conductivity of 13×10^{-5} mhos., indicating less than 100 parts per

Figure 15. Clean water in Johnson Hollow.

million (very low) soluble salts. Iron, nitrogen, and sulfates were very low. However, on the same date, water in the main channel of the creek, receiving headwater from recent mining operations showed a pH of 3.5 and electrical conductivity of 32×10^{-5} mhos., interpretable as 250 parts per million (medium) soluble salts. Iron concentration was 4.9 parts per million, nitrogen (as ammonia) was 1 part per million, and sulfates were 154 parts per million (medium).

gure 16. **Improved pasture on straightened reach of Brains Creek below Peters spoil, Gladesville Neighborhood.**

ENERAL COMPARISON: SPOILS VERSUS SOILS

Comparing natural soils and old (70 to 130 years old) iron ore spoils, several nclusions were reached: natural soil had distinctly lower bulk densities; higher al porosity at all depths; stronger aggregation or soil structure development; ;her nitrogen and organic matter contents; generally higher water intake (both / and wet); silt loam, loam or light clay loam surface soil textures versus shaly y loams for the spoils; less mica and more vermiculite in strongly acid soil n in comparable spoil; similar field moisture tensions in the top two feet of pth; plant rooting zones of 26 to 36 inches in natural soils versus rooting pths of 72 inches or more in spoils; higher cation exchange capacity and her basic nutrients (Ca, Mg, K) in the top one or two inches of natural soils; below two inches, higher exchange capacities and higher basic nutrients in spoil; significantly more phosphorus in plants grown on spoils than on ural soils; deeper and more abundant total rooting of forest trees on spoils n on natural soils; no consistent differences in forest site quality (based on height growth) between natural soil and old spoils during their history; more irable forage species and slightly higher clipping yields on untreated spoils 1 on untreated natural soils; no present evidence of stream pollution with

sediment or solutes by the spoils compared to soils; and gentle slopes on spoil benches but steeper high wall cuts and over-slopes (spoil edges).

Obviously, these several differences between natural soils and old iron ore spoils should be considered in planning short-time and long-time use of various mine spoil lands. In general, mine spoils appear better suited for growth of permanent vegetation than for cultivated crops. Texture and structure as well as nitrogen nutrition are relatively unfavorable for cultivated cropping of young spoils.

With long-lived vegetation, the greater depth for plant rooting and moisture holding capacity, as well as higher continuous nutrient release from rock weathering should favor many mine spoils compared to natural soils, especially for growth of deep rooted legumes or trees with low nitrogen requirements.

Eluviation of fine near-surface clays is a process of soil genesis in this region tending toward improved surface soil textures and stronger subsoil structure. Accumulation of soil organic matter, nitrogen and microbial activity are other typical processes involved in soil genesis. On the other hand, mine spoil, if properly placed to avoid exposure of plant toxins and excessive stones, can provide deeper zones for plant rooting as well as higher release of certain essential plant nutrients. Thus, over long periods of time, it is logical to predict that natural processes will develop better soils on properly placed mine spoils than can be expected from natural weathering of resistant sandstones and shales in place, where the usable rooting depth to solid bed-rock commonly ranges from 18 to 40 inches on slopes that often are excessively steep for preferred uses.

These conclusions refer only to potentially non-acid or moderately-acid spoils. If mono- and disulfides, or other minerals capable of forming extreme acidity and toxicity, are exposed to oxidation near the surface of spoil deposits, the immediate quality and long-time potentials of the spoil are likely to be inferior to natural soils for the foreseeable future.

Summary

Uncertainty about the short-time and long-time use and potentials of various mine spoils of West Virginia resulted in studies of 70 to 130 year old shaly Pennsylvanian age iron ore spoils in neighborhoods northeast and southeast of Morgantown, involving comparisons with natural contiguous soils and prevailing soil forming processes.

Determinations included bulk densities, porosities, soil structure development, coarse particles, textures of fines, pH profiles, nitrogen and organic matter, cation exchange relations, mineralogy of coarse and fine fractions, dry and wet infiltration rates, growing season moisture tension trends with depth, composition of paired plant leaf samples, root depths and abundance, forest site qualities based on selected tree species growth, pasture forage species plus yields, drainage water quality, and surface slopes.

Natural soil proved superior to old spoils in bulk densities (lower), porosity (higher), soil structure development, infiltration, nitrogen or organic matter especially near the surface, surface texture (more loamy), and smoother land surfaces.

Mine spoils were superior in depth for plant rooting, total available water holding capacity, certain plant nutrients derived from rock minerals (resulting in significantly higher phosphorus in plant leaves grown on spoil); and gentler slopes on spoil benches.

Other comparisons including forest site quality, pH, and mineralogy were not greatly different between natural soils and mine spoils.

Results encourage that properly placed mine spoils can provide rooting depths, plant nutrients, and a weatherable mineral matrix necessary for development of soil profiles superior for many purposes to soil profiles formed by natural processes alone.

Properties noted emphasize that spoils may be equal or superior immediately for perennial legumes or other perennials with moderate nitrogen requirements, but are likely to be inferior for annual cultivated crops or perennials sensitive to nitrogen deficiencies.

Reduced sulfur minerals and other extreme acid-forming, water-polluting, or plant-toxic compounds apparently were absent or exposed only as traces in the iron ore spoils studied.

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Appendix

TABLE 1. Soil mechanical separate percentages for undisturbed surface soils adjoining several mine spoil units.

	Peters		Massey		Glen		Chestnut Ridge		Johnson Hollow		Quarry Run	
Fraction*	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2	#1	#2
Sand	32.8	34.0	34.8	32.8	30.4	26.4	46.4	40.4	42.0	44.8	32.8	34.4
Silt (total)	52.4	50.0	49.8	49.9	35.2	52.0	34.0	40.0	44.2	41.8	44.0	41.7
Silt (fine)	2.4	2.0	3.4	1.5	1.2	6.0	6.0	6.0	5.8	5.8	4.0	6.1
Clay	14.8	16.0	15.2	17.2	35.4	21.6	19.6	19.6	13.6	13.2	23.2	24.0
Textural Class	silt loam	silt loam	loam	loam	clay loam	silt loam	loam	loam	loam	loam	loam	loam

*Sand (2.0 – .05 mm.)
Total silt (.05 – .002 mm.)
Fine silt (.005 – .002 mm.)
Clay (< .002 mm.)

Coarse fragments (> 2 mm.) are not included in these standard mechanical analyses.

'ABLE 2. Nitrogen percentages of total spoil and soil from six-inch deep core samples, showing conversions to acre basis, for six units.

Area	Phase	Sample No.	Nitrogen oven-dry wt. basis	Bulk Density	Weight of 6-inch Acre	Nitrogen per 6-inch acre
			per cent	gm/cc	pounds	pounds
hestnut Ridge	Spoil	1	.091	1.513	2,062,866	1,877
		2	.097	1.516	2,066,957	2,005
		3	.145	1.436	1,957,883	2,839
		4	.150	1.466	1,998,785	2,998
	Control	1	.206	0.956	1,303,437	2,685
		2	.233	9.867	1,182,092	2,754
		3	.242	0.892	1,216,178	2,943
		4	.254	0.865	1,179,265	2,995
hnson Hollow	Spoil	1	.102	1.338	1,824,267	2,861
		2	.141	1.429	1,948,339	2,747
		3	.123	1.469	2,002,876	2,463
		4	.109	1.440	1,963,336	2,140
	Control	1	.388	0.752	1,025,298	3,987
		2	.198	1.035	1,411,148	2,794
		3	.254	0.906	1,235,266	3,137
		4	.200	0.918	1,251,627	2,503

APPENDIX

TABLE 2. (continued)

Area	Phase	Sample No.	Nitrogen oven-dry wt. basis	Bulk Density	Weight of 6-inch Acre	Nitrogen per 6-inch acre
			per cent	gm/cc	pounds	pounds
Quarry Run	Spoil	1	.093	1.530	2,086,045	1,940
		2	.116	1.466	1,998,785	2,318
		3	.067	1.598	2,178,758	1,460
		4	.094	1,470	2,004,239	1,884
	Control	1	.119	1.186	1,617,026	1,924
		2	.128	1.100	1,499,771	1,920
		3	.154	1.087	1,482,046	2,282
		4	.134	1.126	1,535,220	2,057
Peters	Spoil	1	.122	1.340	1,826,993	2,229
		2	.093	1.451	1,978,334	1,840
		3	.170	1.332	1,816,086	3,087
		4	.125	1.524	2,077,864	2,597
	Control	1	.158	1.130	1,540,674	2,434
		2	.166	1.225	1,670,199	2,772
		3	.154	1.187	1,618,389	2,492
		4	.248	0.995	1,356,661	3,364

ꞏBLE 2. (continued)

Area	Phase	Sample No.	Nitrogen oven-dry wt. basis	Bulk Density	Weight of 6-inch Acre	Nitrogen per 6-inch acre
			per cent	gm/cc	pounds	pounds
Glen	Spoil	1	.127	1.401	1,910,163	2,426
		2	.072	1.276	1,739,734	1,253
		3	.083	1.532	2,088,772	1,734
		4	.087	1.363	1,858,352	1,617
	Control	1	.149	1.012	1,379,789	2,056
		2	.135	1.013	1,381,152	1,864
		3	1.38	1.025	1,397,514	1,928
		4	.180	0.989	1,348,430	2,427
Massey	Spoil	1	.129	1.560	2,126,948	2,744
		2	.137	1.603	2,185,575	2,994
		3	.119	1.483	2,021,964	2,406
		4	.088	1.655	2,256,473	1,986
	Control	1	.176	1.086	1,480,683	2,606
		2	.154	1.236	1,685,197	2,595
		3	.170	1.113	1,517,495	2,580
		4	.184	1.038	1,415,238	2,604

APPENDIX

TABLE 3. pH profiles of Peters mine spoil in grass pasture near Gladesville.

Depth	Pit Designations								
(Inches)	1A	1B	2A	2B	3A	3B	5A	5B	Mean*
0-1	6.05	5.85	5.55	5.90	6.00	5.75	5.00	5.45	5.69
1-2	5.15	5.45	4.85	4.90	5.75	5.45	5.20	5.15	5.24
2-4	5.15	5.25	4.95	4.80	5.75	5.40	5.00	5.20	5.19
4-6	5.15	5.10	4.95	4.82	5.50	5.40	4.95	5.20	5.13
6-8	5.15	5.10	4.90	4.70	5.45	5.25	4.90	5.10	5.07
8-11	5.20	5.05	4.80	4.70	5.45	5.10	5.00	5.20	5.06
11-14	5.15	5.10	4.80	4.78	5.50	5.20	5.00	5.20	5.09
14-17	5.05	5.15	4.75	4.80	5.40	5.25	5.15	5.05	5.07
17-20	5.10	5.15	4.75	4.75	5.30	5.10	5.05	4.85	5.01
20-23	5.10	5.25	4.70	4.70	5.40	5.05	5.00	4.95	5.02
Mean	5.22	5.25	4.90	4.88	5.55	5.30	5.02	5.13	5.16

TABLE 4. pH profiles of Chestnut Ridge mine spoil in forest.

Depth (Inches)	Profile Number 1A	1B	2A	2B	3A	3B	4A	4B	Mean*
0-1	4.23	4.62	4.42	4.28	4.26	4.25	4.36	4.21	4.33
1-2	4.08	4.32	4.15	4.24	4.30	4.62	4.50	3.85	4.26
2-3	4.15	4.40	4.40	4.27	4.49	4.62	4.42	4.50	4.41
3-4	4.13	4.60	4.60	4.35	4.55	4.51	4.38	4.45	4.45
4-5	4.24	4.50	4.60	4.41	4.66	4.30	4.23	4.52	4.43
5-6	4.20	4.34	4.64	4.50	4.76	3.80	4.34	4.52	4.39
6-7	4.24	4.41	4.66	4.60	4.12	4.41	4.23	4.44	4.39
7-8	4.31	4.38	4.60	4.59	4.89	4.60	4.16	4.55	4.51
8-9	4.35	4.42	4.55	4.60	4.80	3.10	4.20	3.85	4.23
9-10	4.35	4.50	4.60	4.30	4.78	4.88	4.51	4.20	4.51
10-11	4.30	4.95	4.62	4.65	4.92	5.06	4.18	4.45	4.64
11-17	4.40	4.81	4.46	4.65	3.16	5.10	4.25	3.99	4.35
17-23	4.60	4.65	4.48	4.60	5.07	4.99	4.44	4.31	4.65
Mean	4.28	4.53	4.52	4.46	4.52	4.48	4.32	4.30	4.42

*Depth means are not significantly different, 5 per cent level.

APPENDIX

TABLE 5. Final 60 minute infiltration rates, wet run.*

		TREATMENT	
Unit	**Plot**	**Spoil In./Hour**	**Normal Soil In./Hour**
Johnson Hollow	1	1.9	7.6
	2	1.3	4.7
	3	5.6	9.6
	4	3.1	12.4
	5	5.7	8.4
	Mean	3.52	8.54
Quarry Run	1	10.9	7.4
	2	1.6	11.4
	3	5.5	4.4
	4	24.3	7.1
	5	2.8	2.9
	Mean	9.00	6.64
Peters	1	6.6	21.2
	2	4.2	19.5
	3	4.2	15.0
	4	10.9	23.4
	5	9.2	19.7
	Mean	7.02	19.76
Overall Mean		6.51	11.65

*Significant differences between means Johnson Hollow soil > spoil (5 per cent level); Peters soil > spoil (1 per cent level); Peters soil > Johnson Hollow soil and Quarry Run soil (1 per cent level).

TABLE 6. Precipitation in inches, Brandonville, West Virginia.*

Year	May	June	July	Aug.	Sept.	May to Sept. total	Oct.	Nov.	Dec.	May to Dec. total
Normal	4.64	4.88	5.26	4.61	3.84	23.23	3.92	3.31	4.02	34.48
19[illegible]	3.39	1.39	2.23	1.48	2.09	10.58	0.55	1.10	2.84	14.98
19[illegible]	2.93	4.16	2.73	12.23	2.30	24.35				
19[illegible]	3.70	4.84	3.30	4.28	2.81	18.93				
19[illegible]	9.00	5.91	6.28	9.22	4.58	34.99				

*From R. O. Weedfall, State Climatologist, ESSA, U. S. Department of Commerce, Morgantown, W. Va.